Comparison of Magnetotelluric Inversion Techniques on a Mineral Prospect in Nevada

EM2.5

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SUMMARY

A test of a new magnetotelluric profiling technique has been carried out for the geoelectric evaluation of a mineral prospect in the Carlin Gold District in Nevada. The field procedure consisted in deploying three orthogonal dipoles together with a pair of orthogonal magnetic sensors at each instrumental set-up. This configuration was moved sequentially along the profile at a constant interval of 300 m. Electric and magnetic field data were gathered at 23 frequencies in the band from 0.3 to 350 Hz, and these were reduced to full tensor impedances. The principal tensor impedance component relating tangential electric field to orthogonal magnetic field along the profile (TM) was inverted into an estimate of the resistivity distribution via three different techniques. Inversion results compare well and exemplify the favorable capabilities of magnetotellurics in mapping geoelectric structure in the upper few hundred meters.

INTRODUCTION

The development of portable broadband magnetotelluric (MT) systems has led to new applications of this method in mineral exploration surveys. A test of a new profiling technique for mapping resistivity to a depth of 1.0 km has been carried out in the Carlin Gold District in Nevada. The goal of geophysical exploration in this region is to delineate physical properties which may be related to rock alteration brought about by mineralizing fluids. This mineralization has been controlled by faults and fracture zones that cross mapped contacts between different rock units. A generalized cross section perpendicular to regional strike for the area of this study is shown in Figure 1.

FIELD PROCEDURE

A traverse line of contiguous MT stations was laid out on the section of Figure 1, where for convenience of reference the x- and y-axes are chosen parallel and perpendicular to the survey profile, respectively. The electrode configuration is also shown in this figure; three orthogonal dipoles were processed simultaneously with a pair of orthogonal magnetic sensors. This set-up was moved sequentially down the line, advancing 300 m each time. Electrode separation in the traverse direction was 100 m and the survey covered 4.7 km. The frequency band was 0.3 to 350 Hz. The survey was conducted in December, at a time of low natural field signal in this band. The MT data were acquired without remote reference; vertical fields were measured at only two sites. The operating procedure was to move and complete data acquisition in a maximum of two hours; four set-ups were easily acquired in one day. Using the full 10-channel capability of the acquisition system and operating in times of higher signal it would be reasonable to expect coverage of 1.5 to 2.0 km per day.

DATA PROCESSING

The raw data from this survey consists of the auto- and cross-spectra files for the eight channels of each set-up. MT tensor impedances were calculated for each site using orthogonal electric dipoles from the adjacent site as a 'remote' reference. The orthogonal magnetic sensors were common to the impedance calculation for each of the three orthogonal electric dipoles of each set-up.

The apparent resistivity and phase of the off-diagonal elements of the impedance tensor were chosen for analysis because, (1) The impedance strike was close to the azimuth of the line for most of the stations, and (2) the tipper strike at the only sites where vertical field was measured, was perpendicular to the line. Based on the latter observation, it was assumed that the electric field orthogonal to the profile direction was parallel to an effective regional strike and consequently the Zyx impedance component was the TE-mode impedance. The Zxy impedance component, on the other hand, was the TM-mode impedance. Both Zyx and Zxy impedances were subjected to a very rough editing process. Frequency samples for which the multiple coherence between the measured and predicted electric fields was less than 0.5, or points that were obvious outliers were dropped from the data set. Figure 2 shows the apparent resistivity pseudosection of the Zxy (TM) impedance along the profile. Evident from this pseudosection is the high station-to-station correlation in the measurements. Also, the general nature of the geoelectric structure in the subsurface is easily seen in the slowly changing response patterns along the line.

INVERSION RESULTS

To establish a comparison benchmark, we first inverted the Zxy impedances along the profile using the Bostick one-dimensional (1-D) pseudoinverse; the result of this exercise is shown in Figure 3 in the form of a resistivity section, where the major structural patterns can be recognized at first glance. The variable nature of the surface profile generated from the Bostick pseudoinverse (prominent on the upper right-hand side of the section) reflects the variations in the shallowest depth of penetration; given that the highest frequency is constant for all the stations, the shallowest resolvable depth at a given point along the profile will vary in direct proportion to the surface resistivity. We point out that static effects in the frequency band under consideration were minimal for all practical considerations, as can be seen in Figure 3.

We then used three techniques suitable for the inversion of TM data to reconstruct the conductivity distribution beneath the line from the Zxy impedance components. The first of these techniques, known as the two-dimensional (2-D) Occam's Inversion (deGroot-Hedlin and Constable, 1989), aims at a constrained, maximally smooth, resistivity model in an iterative fashion performing successive 2-D forward computations with the algorithm of Wannamaker et al. (1986). Figure 4 shows the resistivity section obtained by inverting the Zxy impedances with the Occam's Inversion. Due to memory and CPU time constraints, only 10 frequency samples of a total of 16 sites were the data fed into the inversion process.

The second inversion procedure, known as the Rapid Relaxation Inverse (RRI), is a fast iterative technique which uses successive pseudo-1-D inverses at each site coupled with approximate horizontal field derivatives at depth to refine a 2-D finite difference model (Smith and Booker, 1990). In this case, the whole data set was used in the inversion, and the results are shown in Figure 5. Finally we applied the adaptive spatial filtering procedure described by Torres-Verdin and Bostick (1989) to the Zxy impedance components and simply constructed a conductivity section using the Bostick pseudoinverse on the filtered data. The results obtained following this procedure are shown in Figure 6.

DISCUSSION

All three approaches agree remarkably well in identifying main geoelectric features in the subsurface; this is also true for the 1-D inverted section, although the latter introduces unnecessary lateral variations in the subsurface resistivity. The three methods yield smooth lateral variations in the resistivity distribution, however both the Occam's and RRI results seem to introduce more complex structure at depths below 500 m than the adaptive filtering approach does.

In addition to the MT survey, three controlled source time-domain electromagnetic (TDEM) soundings were conducted at the sites indicated in Figure 1. The agreement with the MT inversion results is excellent and clearly shows that, at least in the upper few hundred meters, the 1-D interpretation of the TM magnetotelluric data is quite accurate provided that static effects are minimal. Evidently, the spatial sampling interval used in the Carlin survey provided the confidence to disregard lateral impedance variations that could have resulted from static effects.

CONCLUSIONS

The results presented here have illustrated that tensor MT can provide excellent resolution of the subsurface resistivity in mineral exploration surveys. We have shown results from three different inversion methods that compared well in the interpretation of a densely sampled MT profile. The inferred subsurface resistivity revealed far more complex structure than found in the mapped geology and provided data that is only now being integrated in a geological model.

ACKNOWLEDGEMENTS

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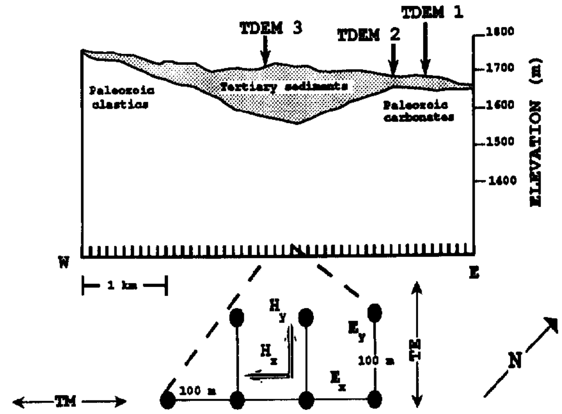

Figure 1. An integrated cross section of the Carlin MT survey profile. Data from a total of 48 contiguous MT stations were acquired with tangential electrode separations of 100 m. In addition, time-domain electromagnetic data were gathered at three inspection points.

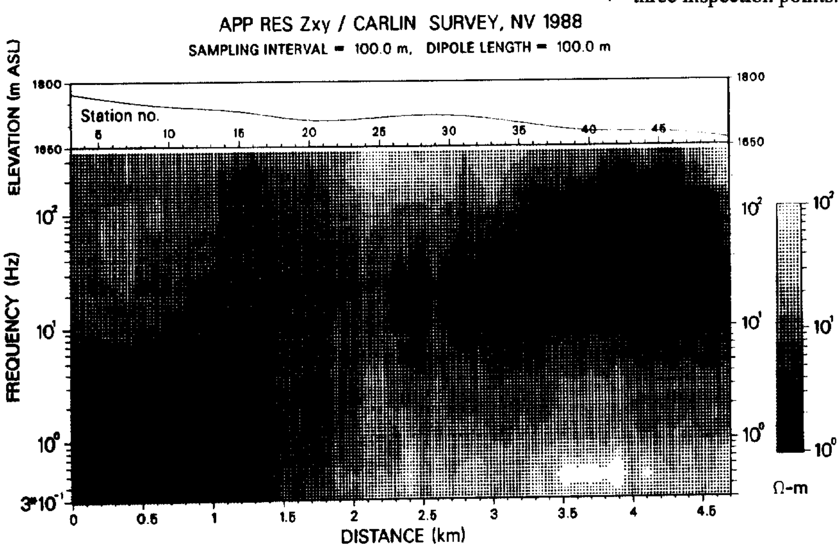

Figure 2. Apparent resistivity pseudosection of the Zxy (TM) tensor impedance component.

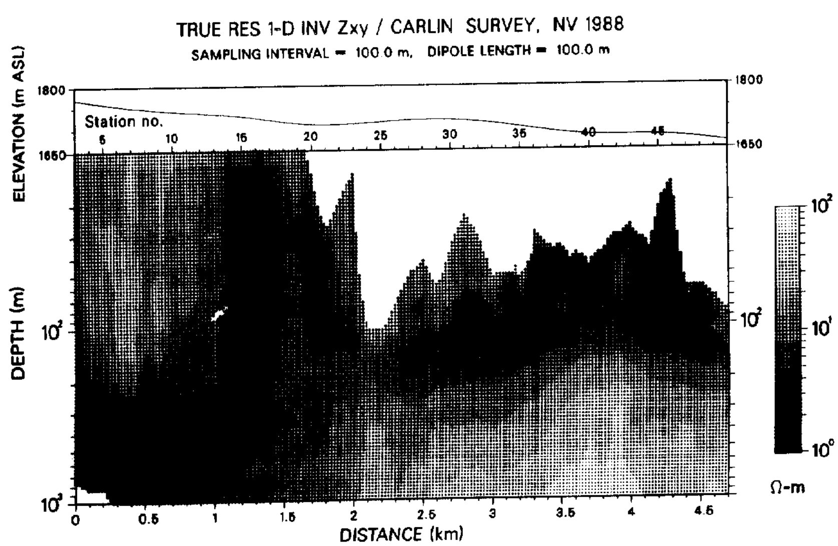

Figure 3. Resistivity section derived by applying the 1-D Bostick pseudoinverse to each one of the Zxy impedances along the profile.

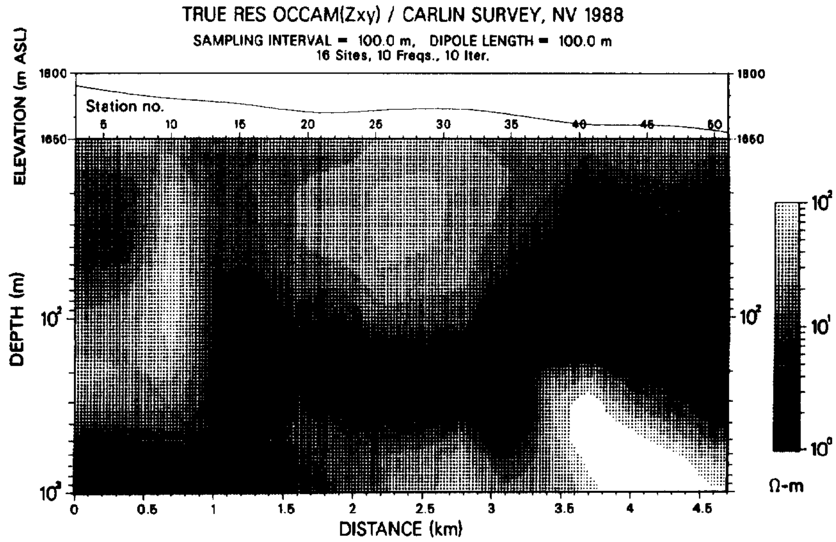

Figure 4. Resistivity section derived from the 2-D Occam's Inversion procedure. Only 10 frequency samples of a total of 16 sites constituted the data set fed into the inversion.

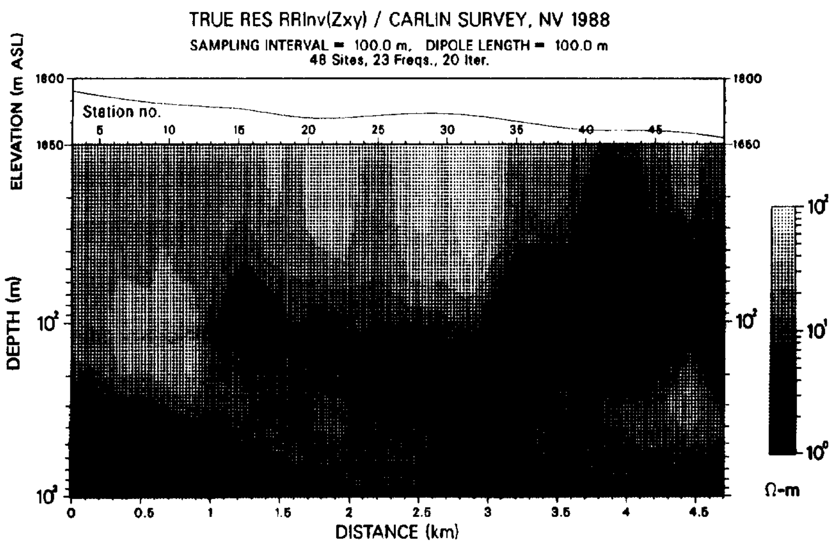

Figure 5. Resistivity section derived from the Rapid Relaxation Inverse procedure. The whole data set (23 frequency samples of a total of 48 sites) were used in the inversion.

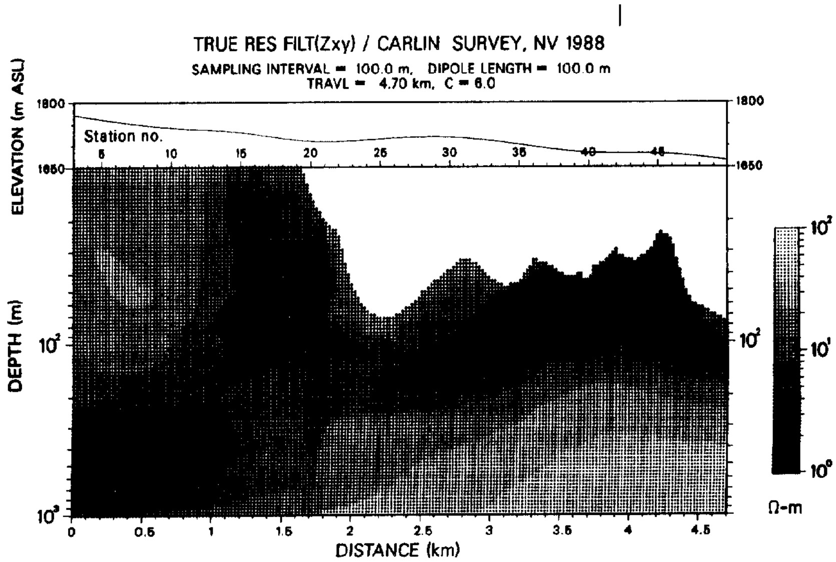

Figure 6. Resistivity section constructed by subjecting the Zxy (TM) impedances to adaptive spatial filtering and subsequently inverting them with the 1-D Bostick pseudoinverse.